APPENDIX

INDIA METEOROLOGICAL DEPARTMENT

WEATHER

AND

THE INDIAN FARMER

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FOREWORD.

This pamphlet on " Weather and the Indian Farmer " is being brought out to acquaint the general public, and the agriculturists in particular, what the India Meteorological Department can do to help the farmer. Plants and crops are largely dependent on the weather during the growing season, particularly during critical phases like " germination ", " flowering ", " harvesting ", etc. Timely warnings against adverse weather phenomena, and information about their duration and intensity are of great value to the farmer, but how to make the information reach the farmer quickly still remains a difficult communication problem in India. A start was made to render some weather service to the farmer with the full co-operation of the All India Radio with effect from the 1st July 1945 ; farmers' bulletins are now becoming a regular feature of the rural broadcast programme of the All India Radio stations in India.

It is hoped that this pamphlet will be useful also to revenue and agricultural officers in the districts, as well as to other government departments and officials concerned with Indian Agriculture.

Dr. L. A. Ramdas, Agricultural Meteorologist, has rendered valuable aid in the preparation of this pamphlet.

POONA;
Dated the 24th October 1945.

S. K. BANERJI,
Director General of Observatories.

WEATHER AND THE INDIAN FARMER.

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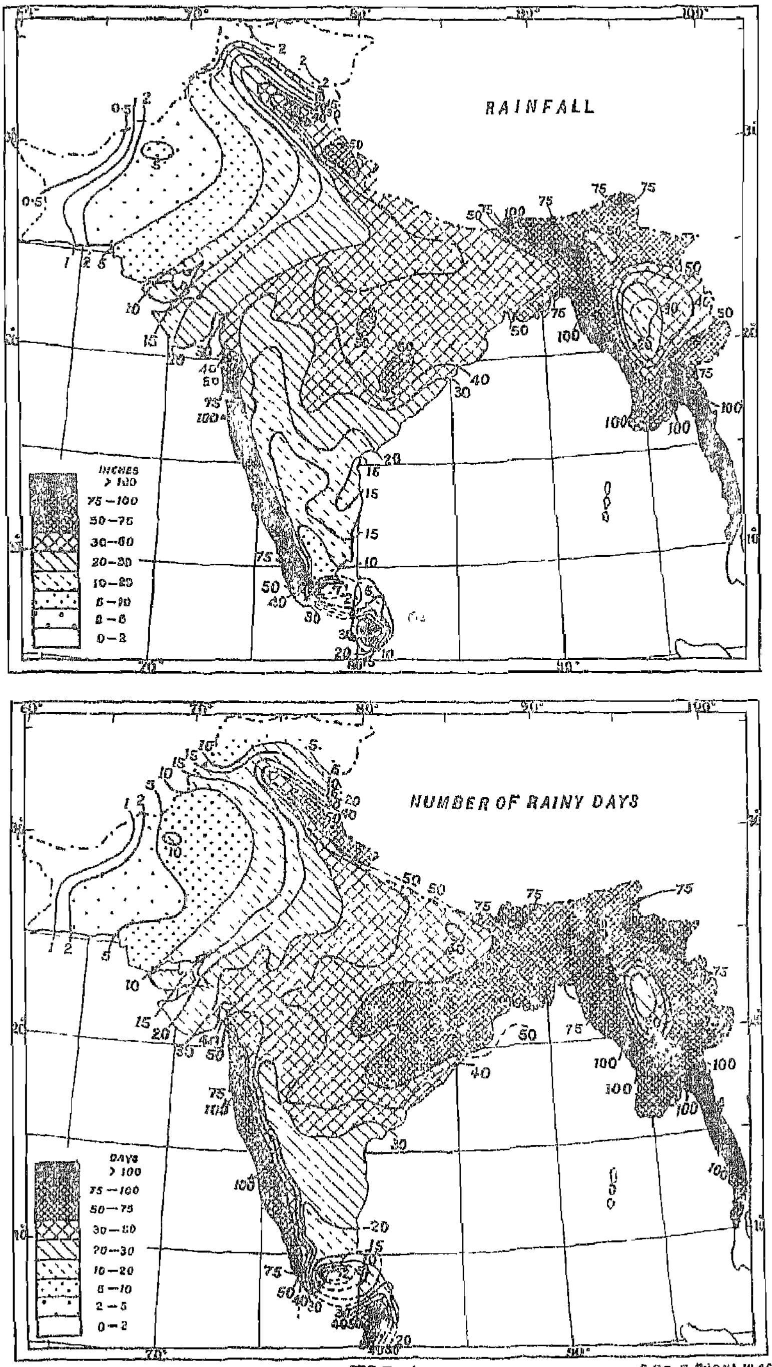


G.P.L.D., POONA, 19-46.

FIG. 1.

SEASONAL RAINFALL AND NUMBER OF RAINY DAYS.
JUNE TO SEPTEMBER.

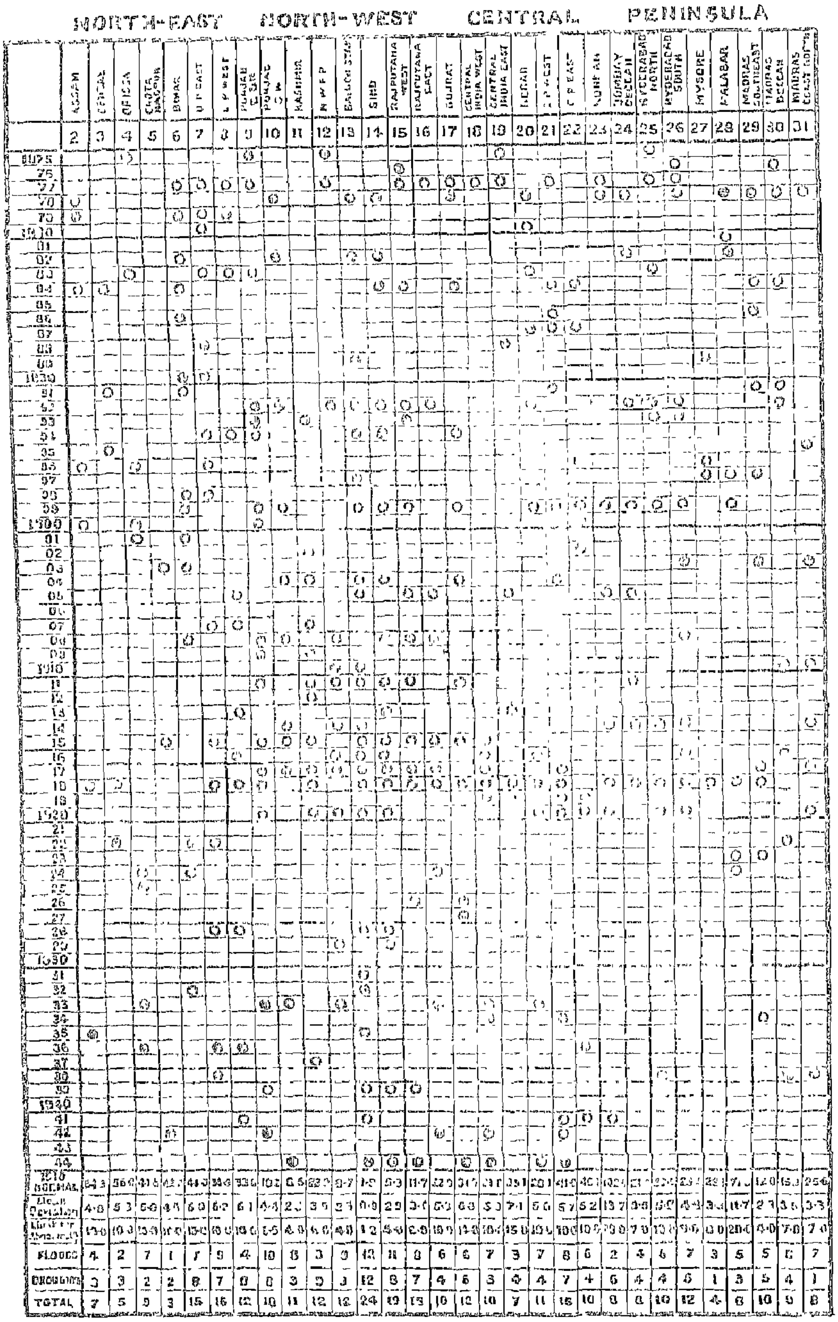


FIG. 2. FLOODS ◉ AND DROUGHTS ○ IN INDIA.

THE FAMINE YEARS OF 1877, 1899 AND 1918 ARE CONSPICUOUS.

Years of floods and droughts have for this purpose been defined as years with anomaly greater than twice the mean deviation.

G.P.I.P.POONA.1940

WEATHER AND THE INDIAN FARMER.

CHAPTER I.

INTRODUCTION.

In India, with her enormous population, the problem of FOOD production is of vital importance. The farmer through the ages has ever prayed to the "rain gods" to shower timely and plentiful rains for his crops. He looks forward to a timely monsoon and a good distribution of rainfall during the year. We may recall a Finance Member's declaration that the Indian Budget is a gamble in the monsoon rainfall!

1. **The growth of "Weather Science".** —To the layman "weather" may appear as one of those inevitable things which must be endured by crops, animals and men alike, when and as it comes. Thanks however to the modern spirit of scientific enquiry, man has made large progress conquering and indeed harnessing nature for his own purposes. Progress in some branches of scientific knowledge has been very rapid and spectacular, but has been necessarily slow in others. The science of Meteorology, for example, though it was one of the earliest to attract attention, may be said to be still in a process of slow but steady development.

The early climatologists began with a study of weather as far as it could be seen and understood from the surface of the earth; but it was soon realised that the "drama of weather" is enacted in three dimensions and that, for a complete understanding of the various "acts" and "scenes" in this vast drama one must explore the whole atmosphere, at any rate, the first 6 to 10 miles above the ground. The atmosphere is indeed a vast thermodynamic Heat Engine with water vapour as its working substance.

One of the most important aims of science is to understand and predict natural phenomena; but the success attained depends on the completeness of our knowledge of all the relevant factors on which the prediction is based. In India the net-work of "surface" observatories has been steadily growing. The number of pilot balloon stations for measuring the velocity and direction of winds in the upper air has been increasing rather slowly. Even so recently as 1939, just before the out-break of war, the use of "Radio-sonde" instruments to signal the temperature and humidity of the upper air was non-existent. Two radio-sonde instruments have since been developed in India and daily soundings are now being made from a number of stations giving a three-dimensional picture of the processes in operation in the atmosphere. With all this increased operational material and the additional weather charts which meteorologists now prepare, they are in a much better position to come to the aid of the farmer than they were ever before.

2. **Liability of India to floods, droughts and storms.**—One who examines the past records, particularly of the last 75 years for which reliable information is available, cannot help noticing that in many years, parts of the country have been subject to famine owing to failure of the rains and that occasionally the entire country has had to suffer this calamity. *Walford* records 34 famines (above 20 on a large scale) in India during the 100 years ending 1879. In recent history the years 1877, 1899 and 1918 will long be remembered as disastrous famine years (due to failure of the monsoon rains).

Fig. 1 shows the distribution of the normal rainfall and of the number of rainy days during the southwest monsoon season, June to September.

The abnormalities of the monsoon season as a whole over the 30 rainfall division into which India has been divided are shown in *Fig.* 2 for the period 1870 to 1940. The normal rainfall and the "mean deviation" for each of the rainfall divisions are given at the bottom of the diagram. Years in which the actual rainfall has been

" above " the normal by about twice the mean deviation are defined as years of FLOODS or excessive rainfall and those in which it has been below the normal by the same amount as years of DROUGHTS or defective rainfall. The open circles [O] are the droughts and the full circles [●] the floods. The blanks denote more or less " normal " rainfall.

It may be seen that the years 1877, 1899 and 1918 stand out as the big FAMINE years, while 1878, 1892 and 1917 are the years in which FLOODS or excessive rainfall occurred over a large part of the country. In two instances at least DROUGHTS and FLOODS occurred, in adjacent years, *viz.*, 1877, 1878, 1917 and 1918. Indeed, a careful examination of this interesting diagram will reveal that though the great famines did occur at intervals of about 20 years, there is no regularity in time or " periodicity " in FLOODS or DROUGHTS. Areas of excess or defect of rainfall are, however, associated into zones of abnormality in the years in which they do occur. Another interesting feature to note is that in a sufficiently long series of years the number of FLOODS and DROUGHTS tend to equalise ; also, areas of low rainfall like Baluchistan, Sind, Rajputana, Punjab North-East and North-West Frontier Province are those where the total number of abnormalities are maximum ; in areas like the Konkan, Malabar or Bengal where the monsoon rainfall is above 40″, the frequency of abnormal monsoons is comparatively small.

Besides rainfall, there are various other large and small scale weather phenomena like storms, cyclones, depressions, thunderstorms, cold waves and frosts, heat waves, high winds, etc., which affect crops and men. We shall deal with these phenomena in the following pages.

CHAPTER II.

THE STUDY OF CLIMATE IN RELATION TO CROP GROWTH AND YIELD.

A scientific study of the influence of weather on crops, or more concisely, Agricultural Meteorology is a recent development in most countries. It is satisfactory to note that active interest in this subject began in India about the same time as in other parts of the world, thanks to the recommendations of the " Royal Commission on Agriculture in India ". A new section to deal with Agricultural Meteorology was started in 1932 at the Meteorological Office, Poona, under the auspices of and with funds provided by the Imperial Council of Agricultural Research, and has since become a permanent activity of the India Meteorological Department.

The aims and objects of this research section are :

(*a*) To conduct experimental work of a fundamental nature in agricultural meteorology and evolve methods, instruments and techniques of investigation which will lead ultimately to an understanding of the processes by which climate affects the growth, yield and the associated pests, diseases, etc., of plants in general and agricultural crops in particular.

(*b*) To examine past data of crop out-turns and weather factors both of which are available in India for a long series of years with the object of

(*i*) studying, as far as the limitations of these data would permit, how weather had affected crop out-turns in the past, and

(*ii*) working out methods of recording in future more accurate and complete information regarding weather factors and the growth and yield of crops.

(*c*) *To undertake particular* investigations on problems in which climate and weather play a part, *e.g.*, incidence of pests and diseases, ability to stand droughts, effect of wind breaks, physics of sub-soil irrigation, etc.

(*d*) To act as a liaison section between meteorology and agriculture :

(*i*) by co-operating with agricultural research workers in India and advising them on the meteorological aspects of their problems, and

(*ii*) by finding out what type of weather forecasts and warnings are most useful to the farmer at large so that the Regional Forecasting Centres of the India Meteorological Department may be told how to issue the most useful type of forecasts and warnings.

(*e*) To promote the study of Agricultural Meteorology and border land problems in meteorology, physics, soil physics, plant physiology, etc. by providing facilities for post-graduate students who wish to take up investigations on these subjects.

Most of the experimental work on the climates of crops, the estimation of the growth and yields of crops by random sampling, soil temperatures, soil moisture, solar and sky radiation, etc., as well as investigation in soil physics, plant physiology, etc., are done at the Central Agricultural Meteorological Observatory at Poona. This observatory is also utilised for training agricultural research workers sent on deputation by the various Provinces and Indian States.

The Imperial Council of Agricultural Research has sanctioned this year a new scheme called " The Co-ordinated Crop-Weather Scheme " to work under the Agricultural Meteorologist. The object of the scheme is to organise systematic crop and weather observations at a net-work of selected experimental farms according to a common plan and on a long-term basis.

With the advice of the Agricultural Meteorology Section at Poona a net-work of farm observatories has grown up and is still growing. These stations are taking part in the scheme referred to above.

CHAPTER III.

WEATHER AND CROPS.

The healthy growth and normal yield of crops depend upon certain *optimum* conditions of rainfall, temperature, humidity, wind, cloudiness, etc., in the air and soil layers with which the plant world is concerned. It is the function of research workers in agricultural meteorology to discover the exact way in which plant growth and yield are dependent upon the meteorological environments. Analysis of existing data has given ample evidence for concluding that of all the " controls ", the climatic factor is the one " control " which accounts for at least 50% of the variability of crop yields over a series of years. Manure, variety, cultural operations, etc., *all combined* account only for the remaining 50% of the variability.

It must be remembered that the march of climatic factors is by no means smooth and regular, as suggested by their normal values, during the growing season. In any single year these factors deviate at random and in varying degrees from the normal values. Often, the fluctuations of weather occur abruptly and with a violence which crops can hardly stand. Thus " weather " while it has a ' benevolent ' aspect upto a degree has also a ' malevolent ' aspect on crops. We may now consider what are the weather abnormalities for which advance warnings and possible protective measures will be necessary.

The major weather abnormalities and destructive meteorological phenomena which can affect crops adversely in India are :—

(*a*) Excessive rains, floods. ⎫
(*b*) Scanty rains, droughts. ⎬ Rainfall.
(*c*) Untimely rains. ⎭
(*d*) Storms, cyclones, depressions.
(*e*) Thunderstorms, hailstorms and dust-storms.
(*f*) Cold waves accompanied by frost.
(*g*) Heat waves.
(*h*) Excessive or defective insolation.
(*i*) High winds.

The main features of these phenomena may be described very briefly. We may also consider how far the destructive effects and loss of property can be mitigated by direct remedial measures or indirectly by affording some relief in other possible ways.

1. **Floods.**--We have referred earlier to the liability of India to the incidence of 'floods', 'droughts' and famines. We may here refer to the incidence of ACTUAL floods which devastate large tracts of the country, particularly in the areas drained by the large river systems of India. Such floods occur usually during spells of very heavy rainfall over the catchment areas. The frequency of heavy rainfall over India has been discussed in a recent paper by Doraiswamy and Mohamed Zafar. The details given below are taken from their discussion. *Fig. 3* is a map of India indicating the frequency of heavy falls of 5″ and above in 24 hours. *Fig. 4* indicates the heaviest fall in 24 hours. Both figures are based on data during the period 1891 to 1920. With reference to the heaviest fall in a day the following conclusions may be drawn from *Fig. 4*.

(*i*) Falls exceeding 5″ in 24 hours have occurred over the whole of India excluding northeast Baluchistan and parts of the North-West Frontier.

(*ii*) Falls have not exceeded 10″ in 24 hours over most of the interior of the Peninsula and of Burma and in a few districts in the central parts of the country.

(*iii*) Falls of 15″ to 20″ in 24 hours have occurred all along the West Coast including Gujarat and Kathiawar, on the South Coromandel Coast, on the North Burma Coast, in South Assam, in Bengal and the foot of the Himalayas.

(*iv*) A few isolated falls of 20″ and over in 24 hours have occurred in the plains.

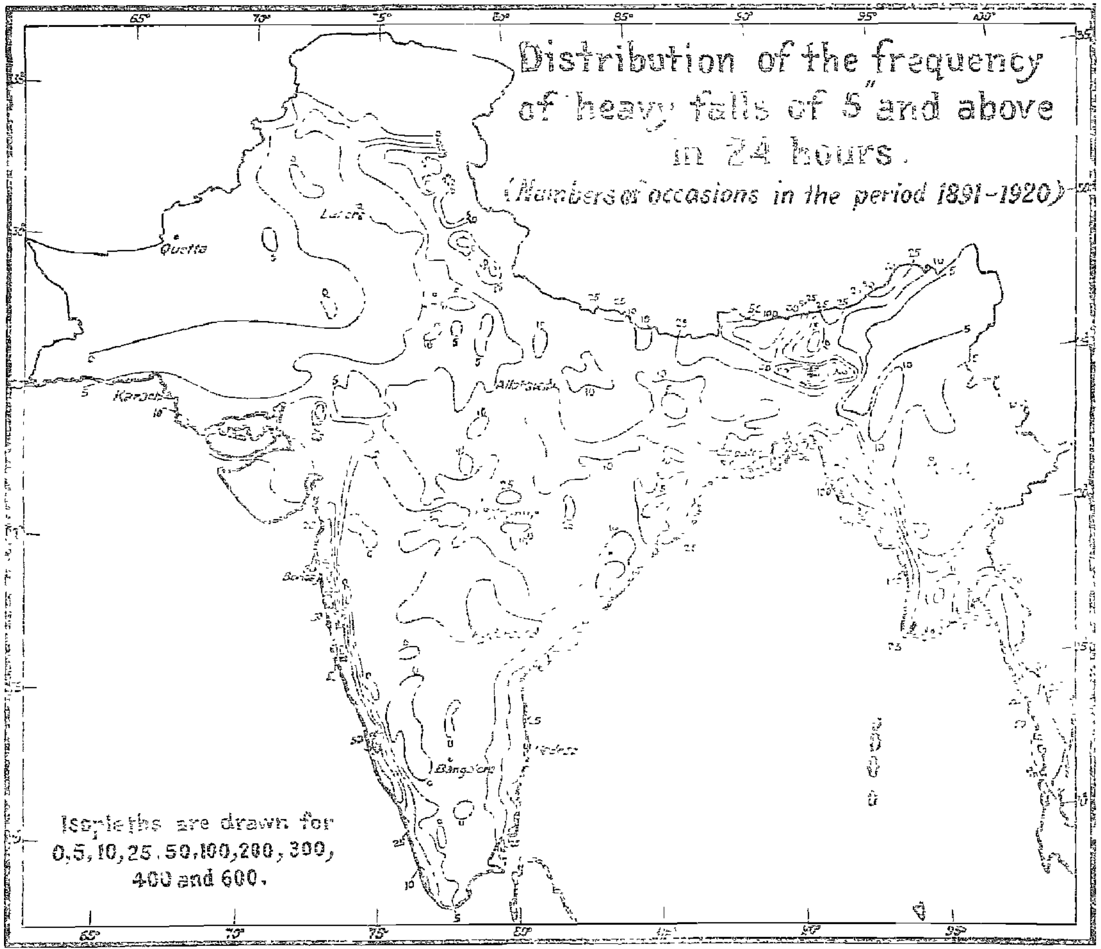
(*v*) The greatest fall of over 40″ in 24 hours has occurred at Cherrapunji in the Khasia Hills.

When heavy rainfall occurs consecutively on a number of days and particularly over the catchment areas of rivers, the magnitude of the ensuing floods may well be imagined. For such large-scale phenomena the remedies depend on large-scale planning and operative measures. Individual floods have been examined, for instance Orissa floods of 1925, North Bengal floods of 1918, Damodar floods of 1913. Attention to improve the natural drainage system by dredging of dying rivers and other measures has been drawn. In the case of Damodar, the development of the catchment area on the plan of the Tennessee Valley in U. S. A. has been proposed. A careful sifting of the facts of forestry in India has revealed that we are paying now for the errors of the past, for the indiscriminate and wholesale destruction of forests. The forest departments are now appreciating the vital importance of a well-developed forest cover over a catchment area for checking erosion and preventing too rapid a drainage of the flood waters into rivulets which discharge into major rivers and their tributaries. By retarding surface drainage, the downrush of the waters is stemmed and the peak of the flood is, as it were, delayed and smoothed over. Planned afforestation of the denuded areas is one of the remedies and the activities of the State in this direction should receive every support.

For floods, the individual farmer can only keep the drainage channels of his fields open. The development of " flood-resistant " varieties of crops is engaging the attention of agricultural workers.

Fig. 5. shows some typical scenes of floods as a result of heavy rainfall.

2. **Droughts.**—The problems raised by *droughts* or prolonged dry spells relate not only to the careful collection of rain-water in a system of tanks, bunds, lakes, etc. and their distribution by a planned system of irrigation, etc., but also to the *conservation* and most economical use of the available water in such reservoirs and in the soil as far as possible.



G.P.Z.I. Poona-1946

FIG. 3.

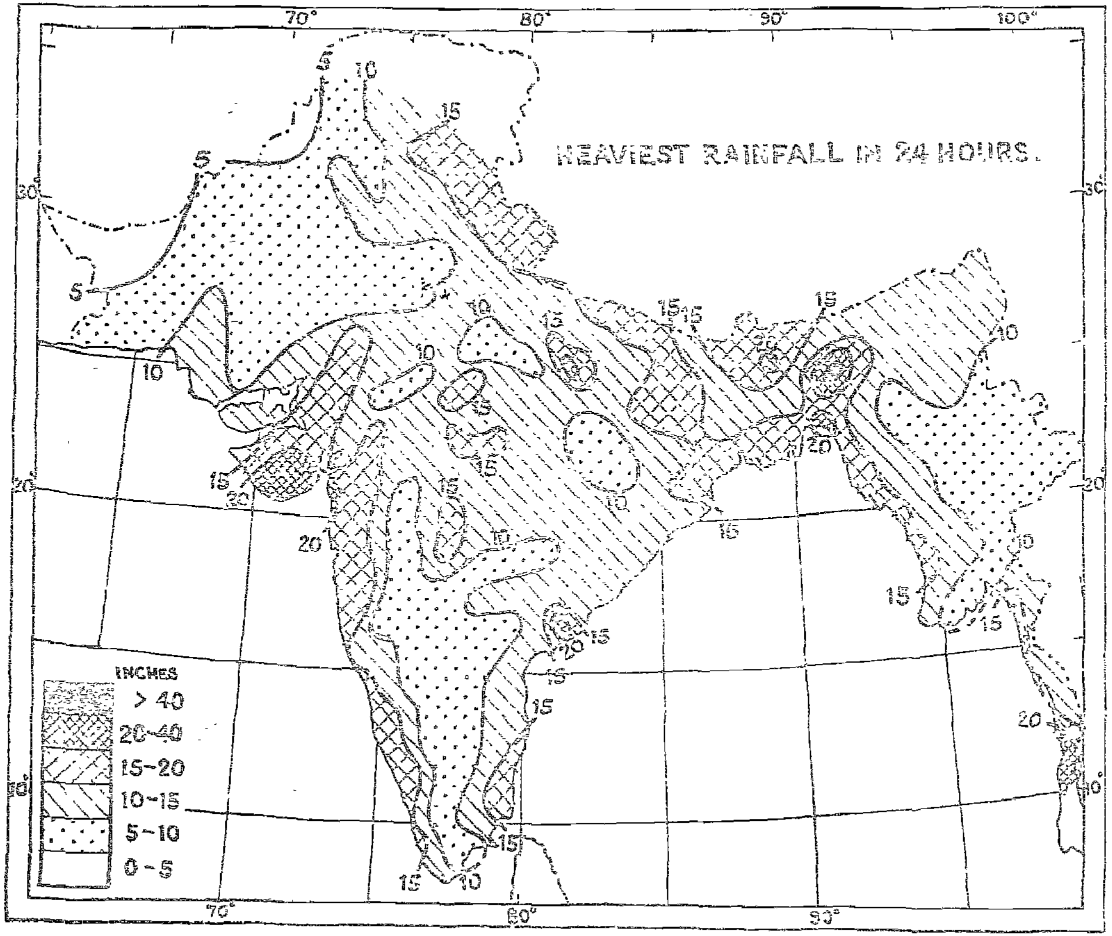
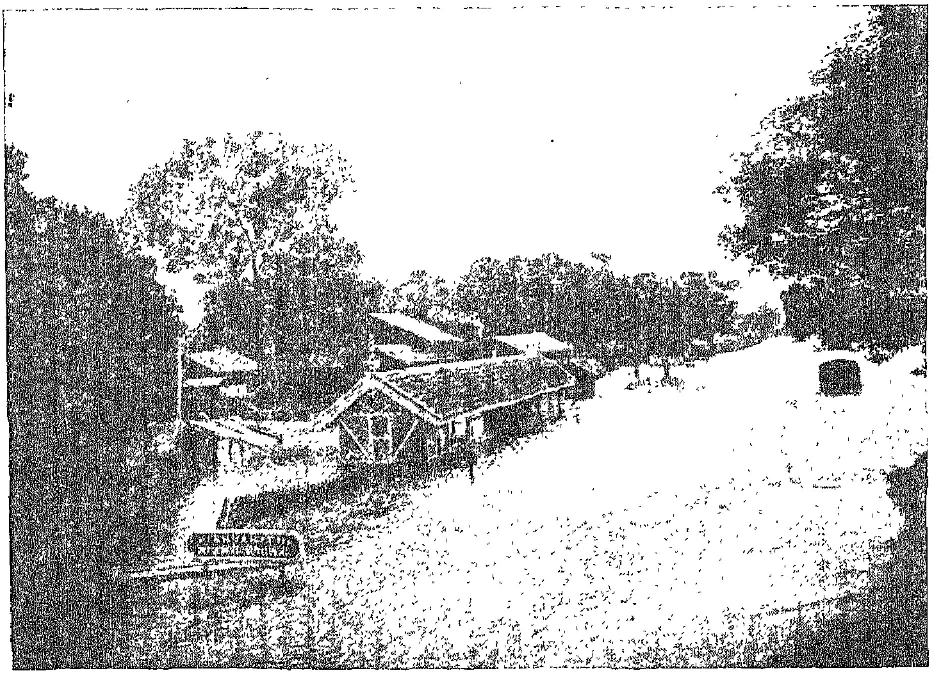
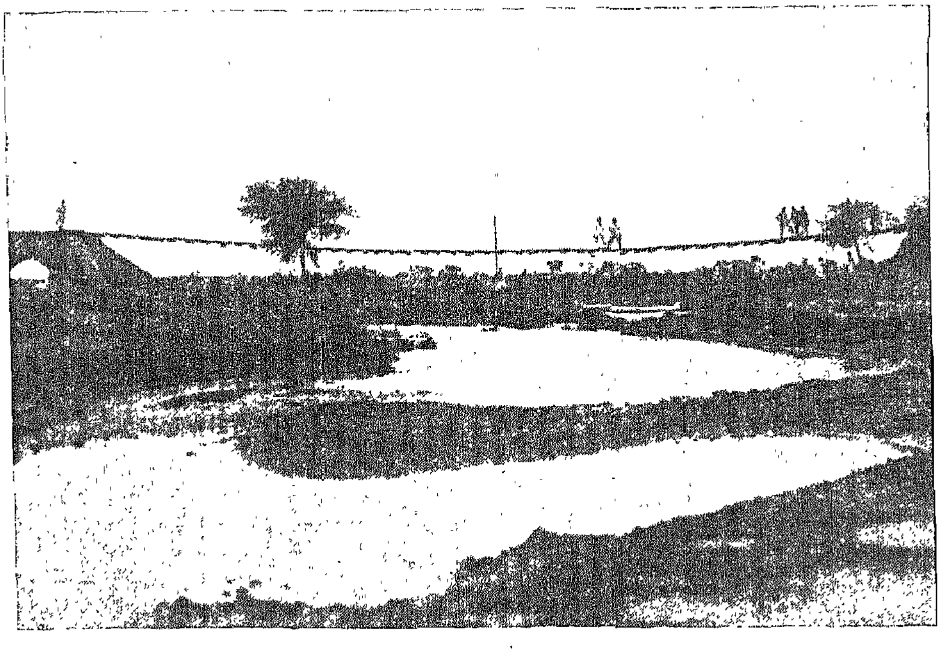

HEAVIEST RAINFALL IN 24 HOURS.
INCHES
> 40
20–40
15–20
10–15
5–10
0–5
70°
80°
90°
100°
30°
20°
10°

FIG. 4.



RAILWAY STATION, BARODA STATE RAILWAY.



RAILWAY EMBANKMENT WASHED AWAY IN KATHIAWAR.

FIG. 5. GUJARAT FLOODS, JULY 1927.

G. P. Z. P. Poona, 1946.

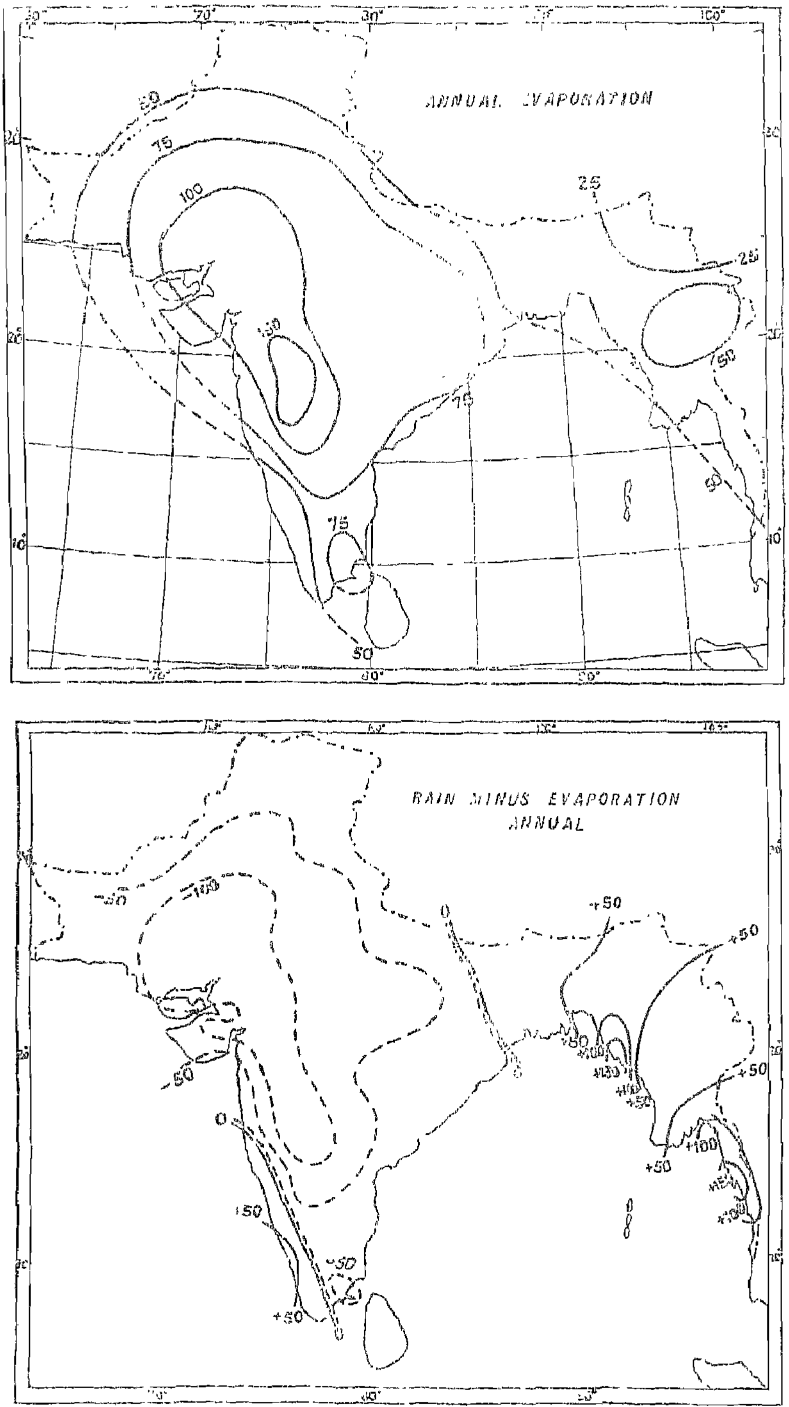


FIG. 6.

G. I. P. Poona, 1946

Wherever *feasible*, resort should be had to sub-soil irrigation, *i.e.*, delivering the water at the root zone of the plants through suitable pipes. In arid parts like Rajputana and Sind, such a system where practicable (*e.g.*, in orchards), would prevent water loss by excessive evaporation (which would occur in the case of surface irrigation) and make the most effective use of the little moisture that may be available.

Methods of conserving sub-soil moisture by surface mulching are in use over dry-farming tracts where droughts are the rule ; but in such areas the soil has a high water-holding capacity. In areas like the alluvial plains of the Indo-Gangetic Valley rain water percolates into the lower layers of the soil. Water in canals, wells, and tube-wells is the only source of moisture in droughty years. If these supplies too fail, there is no remedy. When one reviews this problem it becomes clear that attempts should be made to check evaporation from the soil as well as from water reservoirs. The rate of evaporation is proportional to the wind velocity and saturation deficit. *Fig. 6* shows the mean annual evaporation from a water surface over India. The area of highest evaporation (150″ per year) occurs over the Bombay Deccan. As one moves away from this area, northwards, eastwards or southwards, the rate of evaporation decreases. It is only during the monsoon season that the centre of high evaporation shifts temporarily to Sind. The lower map in *Fig. 6* shows the annual rainfall *minus* evaporation. Note that rainfall exceeds evaporation only along the west coast, Bengal and the Burma coast. Rajputana, Central India and the Bombay Deccan form the big area of excess of evaporation over rainfall (to the extent of 100″ per year). Although we cannot alter the general atmospheric circulation over the country, it is possible to check air movements near the ground by building up a system of wind breaks and so keep down the evaporation loss. We shall refer to the subject later.

In areas which are liable to frequent droughts, drought-resistant or drought-escaping varieties of crops may be introduced.

3. **Cyclonic storms and depressions.**—Besides the setting in of the monsoon early in June, its extension into India during June and July and finally its retreat southwards in September and October, weather in India is affected by other major phenomena like cyclonic storms and depressions.

(*a*) *Eastern depressions.*—The fluctuations in the intensity of the southwest monsoon itself are to a large extent associated with a series of depressions which originate in or pass through the head of the Bay of Bengal and travel across the country in a northwesterly or westerly direction towards northwest India. Heavy rainfall occurs along the tracks of these depressions. The frequency of these depressions is 3 to 4 per month during the monsoon season (June—September).

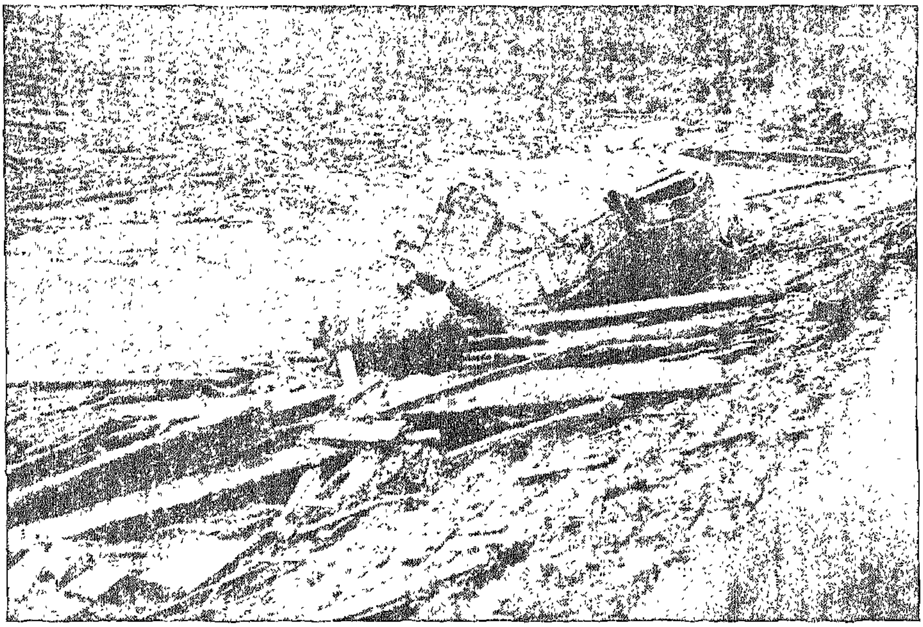
(*b*) *Western depressions.*—During the period November to May, on the other hand, a series of ' western ' depressions enter India through Persia, Afghanistan, Baluchistan and the North-West Frontier Province and move *eastwards* through North India towards Assam. These depressions cause cloudy weather and light rains accompanied by cold waves in winter. Their frequency is on an average 2 in November, 4 to 5 per month during December to April and about 2 in May.

(*c*) *Cyclonic storms.*—The more severe cyclonic storms usually form in the Bay of Bengal and in the Arabian Sea in the transition months—April to June—and October to December. They enter inland and cause heavy rainfall and widespread destruction due to high winds and occasional tidal waves. Their effects are most severe in the coastal tracts. We are all familiar with the very extensive damage to crops, live-stock and human life and property caused by these storms. Their mode of occurrence has been discussed in a series of publications of the India Meteorological Department. On an average 1 or 2 severe cyclones may be expected in the pre-monsoon period and 2 or 3 in the post-monsoon period.

Fig. 7 shows what happened during the great Bombay cyclone of 1940. *Fig. 8* shows the Colaba records of the anemograph (wind velocity and direction), rainfall, air pressure and temperature during the cyclone.

One of the features of the colossal meteorological phenomena like cyclonic storms and depressions is that their favourite directions of movement and speeds are generally understood so that the dates of their onset over a particular locality and the associated heavy rains and squally weather can usually be forecasted. On receipt of the warning, precautionary measures are taken by shipping, aviation, railways, engineering and irrigation interests and so on. Agriculturists can also receive such warnings and take possible steps to save the growing crops, stored grain, live-stock, etc. Warnings of untimely rain and heavy rain, especially during sowing and harvesting periods will be most useful as the date of sowing may be postponed and the harvesting can be hastened, if the incidence of a storm or other large scale weather disturbance is expected. Against the large scale floods and very severe squalls the cultivator can do little, but if forewarned, valuable lives can be saved. The prompt and efficient reception of weather bulletins and warnings against adverse weather by the rural public is a *problem of dissemination* of warnings to which reference will be made later.

4. **Thunder-storms, hail-storms and dust-storms.**—These are comparatively local in character but are often associated with depressions, storms, etc., which affect a larger area. They usually occur before the onset and after the withdrawal of the monsoon. In their mode of occurrence there are points of similarity between thunderstorms and dust-storms and hail-storms. In the absence of sufficient moisture in the atmosphere, we can only get a dust-storm. When enough moisture is present a thunder-storm results. A hail-storm is a particularly violent thunderstorm. Though short in duration, the precipitations and associated squalls during thunder or hail storms are often very violent, *e.g.*, Nor'westers of Bengal. A typical example of a nor'wester in Bengal accompanied by a squall of 80 miles per hour is shown in *Fig. 9*. In many parts of India, *e.g.*, in the Deccan, pre-and post-monsoon thunderstorm rains are the main sources of soil moisture for the growing crop. Hailstorms are, however, very destructive to standing crops and even to live-stock and human beings. By examining the daily records of hail for a period of 35 years (1898 to 1932) and for 140 weather reporting stations in India, charts showing the frequency of days with hail-storm in 100 years for different months of the year and for the year as a whole have been prepared. The frequency of hailstorms is small early in winter but increases generally as the season advances into summer. Once the monsoon sets in, the phenomenon is practically absent in the whole country. After the withdrawal of the monsoon hailstorms begin to occur in the north and central parts of India but, until the winter advances into spring, the increase in frequency is not conspicuous. *Fig. 10* shows the annual frequency of hail-storms in 100 years. The frequency of days with hail is about 10 per year over the Himalayas. This decreases rapidly to once in two years over the adjoining plains. Over lower Bengal the hail-storms occur usually once a year. The area consisting of the Central Provinces and the adjoining districts of Bihar and the United Provinces forms another centre of frequency of the order of once in every year. The coastal tracts of the Peninsula are regions where hail-storms are comparatively rare. The largest known hail stones are about 5 inches in diameter weighing about 1½ pounds. The smaller sizes are more frequent. Hail stones have been reported sometimes to break through ordinary roofs, corrugated iron sheets, etc. Protection against violent hailstorms is therefore difficult, particularly under rural conditions. But the farmer who is warned beforehand can harvest his crops if they are already ripe. The importance of warning for hail-storms may be realised from the fact that in many years in areas like the United Provinces, Central



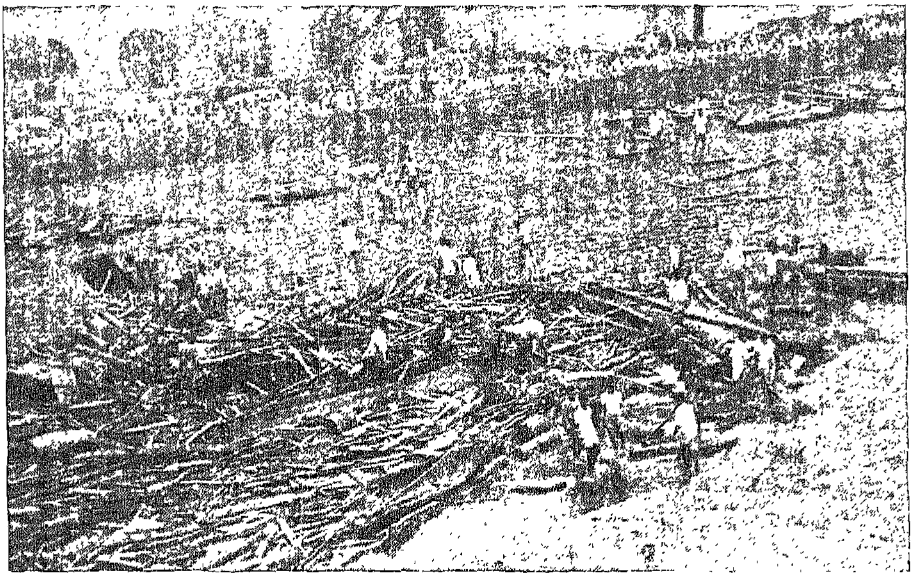


Fig. 7. BOMBAY CYCLONE
HAVOC TO COUNTRY-CRAFT IN BOMBAY HARBOUR

G. P. Z. P. Poona, 1948.

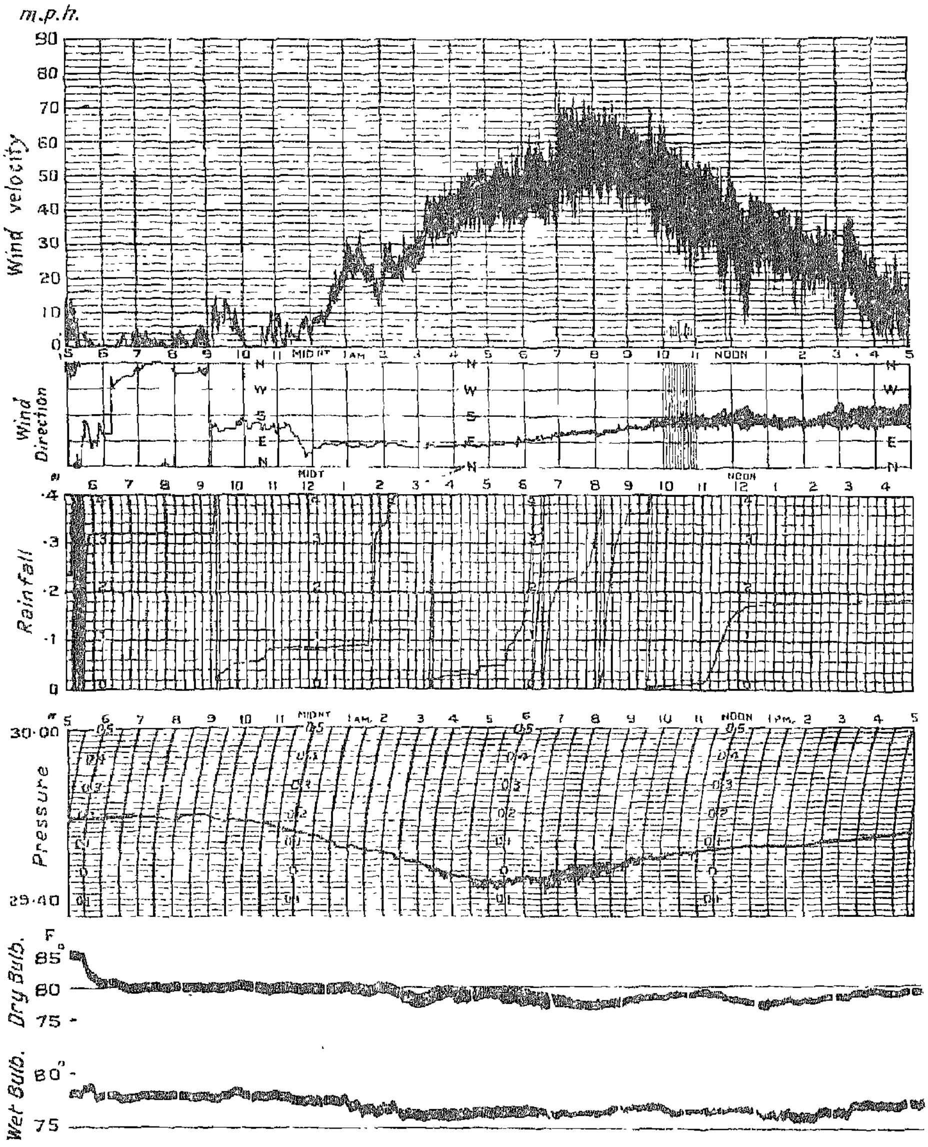


FIG. 8. BOMBAY CYCLONE.

RECORDS OF AUTOGRAPHIC INSTRUMENTS.
WIND REACHED A MAXIMUM VELOCITY OF 75 M.P.H.
ON THE MORNING OF 16TH OCTOBER 1940.

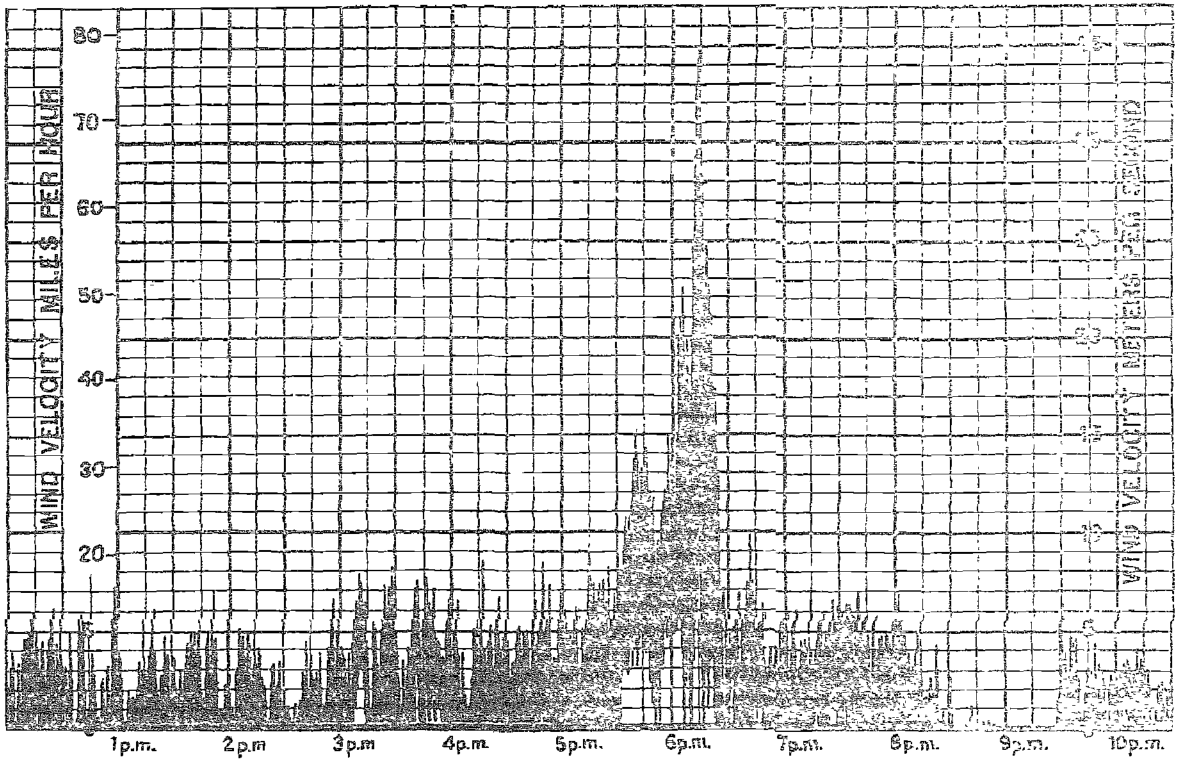


FIG.9 A NOR'WESTER SQUALL (2nd MAY—RAMPUR BOALIA, BENGAL).

Nor'westers are local thunderstorms which occur in south Bengal during the hot weather. They are accompanied by severe squalls which occasionally cause damage to life and property on land and on the rivers. The picture is a reproduction of the trace of a self-recording wind instrument. It shows how, with the sudden onset of the nor'wester, the wind rapidly increased from 20 to about 80 m.p.h. at about 6-15. p.m.

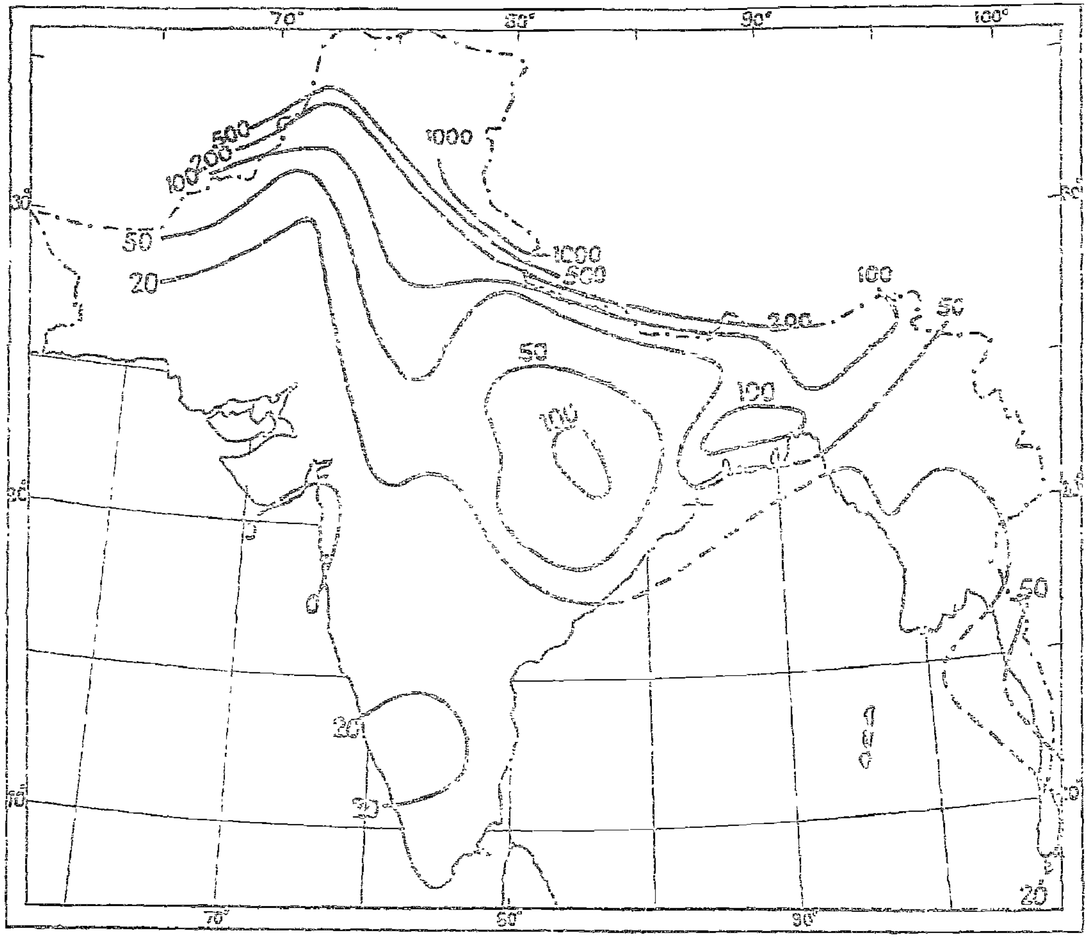


FIG.10. FREQUENCY OF DAYS OF HAILSTORMS IN 100 YEARS (ANNUAL).

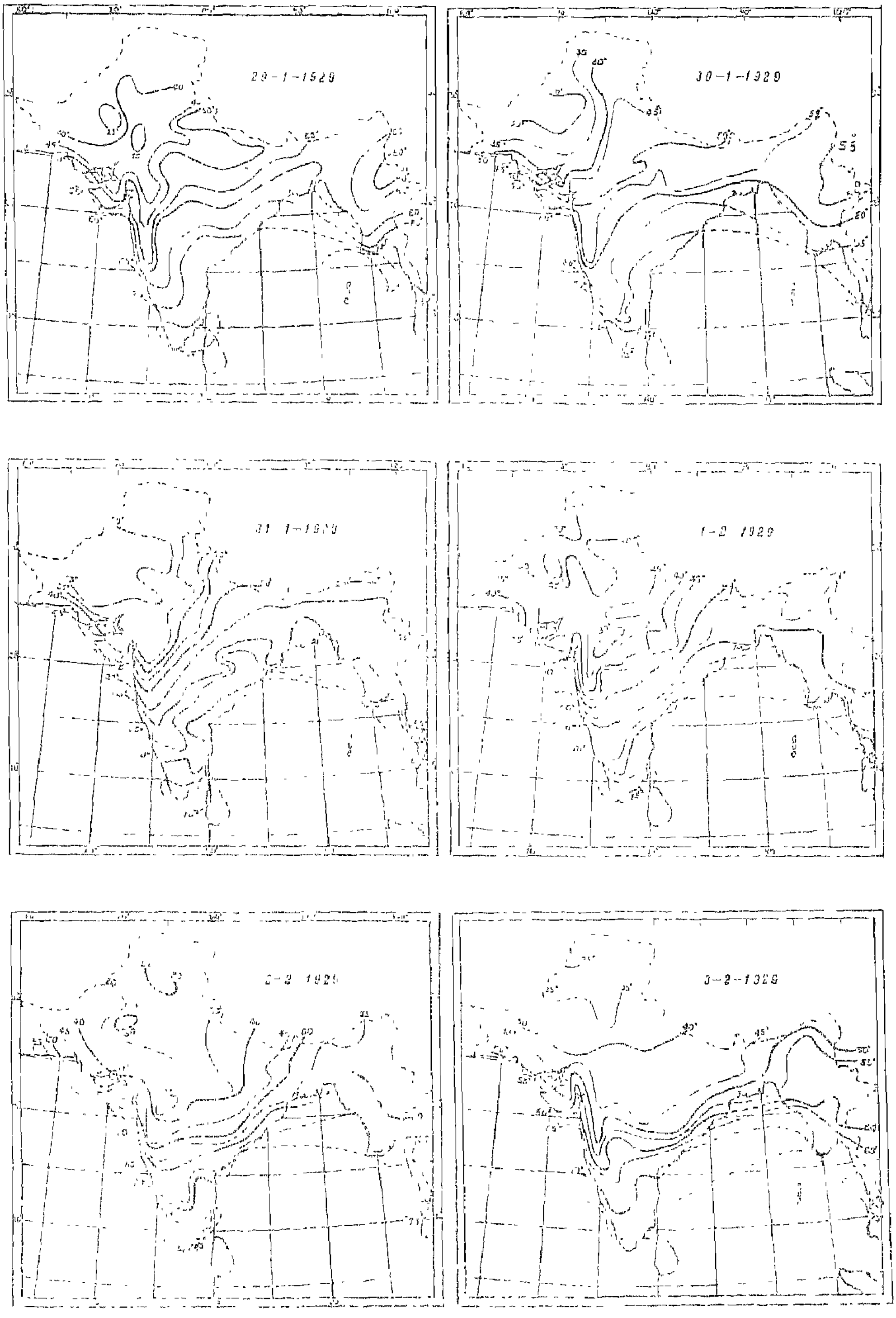


FIG. 2. MINIMUM TEMPERATURE (°F) ON EACH DAY DURING THE PERIOD 29th JANUARY TO 3rd FEBRUARY 1929

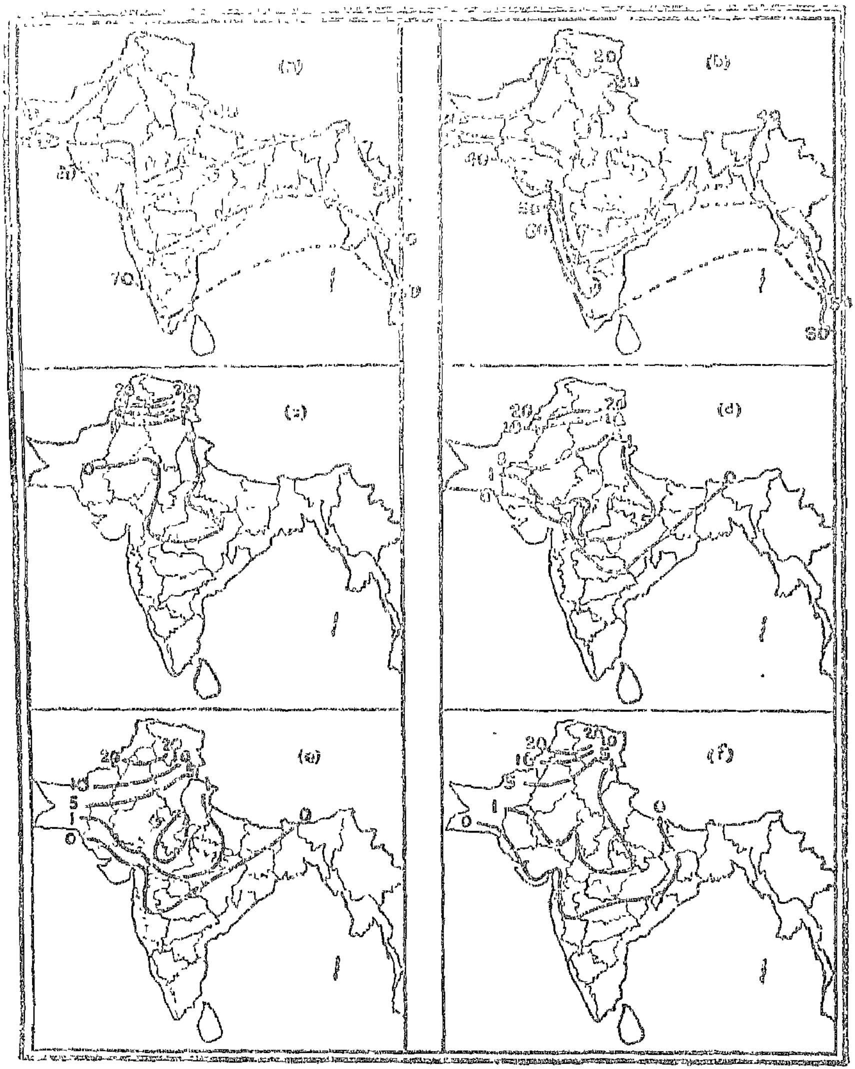


FIG. 12. FREQUENCY OF FROSTS IN INDIA.

(a) Mean daily minimum temperature °F, January
(b) Lowest minimum temperature °F (recorded up to 1920)
(c) Frequency of days with radiation minimum temperature below 30 °F in November
(d) Frequency of days with radiation minimum temperature below 30 °F in December
(e) Frequency of days with radiation minimum temperature below 30 °F in January
(f) Frequency of days with radiation minimum temperature below 30 °F in February

Provinces, Central India, Punjab, and occasionally Bombay Presidency and Hyderabad, the local Governments have to grant large remissions of land tax owing to large-scale destruction of crops by such phenomena.

5. **Cold waves and frost hazard in India.**—During winter, the northern and central parts of India come under the influence of atmospheric disturbances called western depressions. These depressions enter India from the west at intervals of about a week and move eastwards through the Indo-Gangetic plains towards the northeast frontier of India. The approach of a depression is heralded by the appearance of high clouds, movement of air from southerly latitudes and rise of air temperature. Within a day or two, low clouds travel overhead and drizzling weather ensues. So long as the place lies in the warm sector of the depression, there is no danger of low temperatures; but the warm sector moves eastwards and is soon followed by the cold wave, when cold dry winds from the north or northwest, several thousand feet in depth, pour into the region. The cold wave in its turn extends or moves eastwards across the country weakening in the meantime. As soon as another depression approaches the northwest frontier the cold dry northerly air begins to be replaced by warm air from the south and the temperature rises again. The intensity of a cold wave as well as the extent of the country it affects depend upon the intensity and the area of the depression with which it is associated. Sometimes the anticyclone over Tibet and Mongolia which is the main reservoir of cold air for Asia is itself shifted westwards towards Europe and if at the same time a deep western depression passes through Persia and northwest India, a very severe cold wave sets in behind the depression. The phenomenal cold wave which visited India during the period 29th January to 3rd February 1929, was of this type. The six charts shown in *Fig. 11* indicate the minimum temperatures recorded during the above period. *Fig. 12*, (*a*) represents the mean daily temperature in January and (*b*) the lowest minimum temperature recorded up to 1929. A perusal of these two charts indicates that in the regions lying to the north of latitude 16° north, the minimum temperature may sometimes fall by about 20°F below normal whereas to the south of this latitude the corresponding fall will be only of the order of 10°F.

Frost hazard.—It must be remembered, however, that the minimum temperature attained by objects near the ground like crops on a field fully exposed to the sky is about 10°F lower than that attained by the air. The frequency of occasions when the radiation minimum temperature (*i.e.*, the temperature that would be attained by crops) fell below 30°F (below freezing point) in different parts of the country is shown in *Fig. 12* c, d, e and f. From these charts it is clear that the North Punjab is the area most liable to the incidence of frosts—10 to 20 days in each of the months December, January and February. As one moves southwards or eastwards from this tract, the liability to frost decreases rapidly.

Cold wave warnings.—From the daily weather charts prepared at the Regional Forecasting Centres, it is generally possible to give prior warnings for the incidence of cold waves. On receipt of the warning message, a farmer or a horticulturist will know that a cold wave is approaching his station. What steps can he take to save his crops ? Methods of preventing frost damage to crops have, therefore, to be investigated.

It is known that topography has much to do with the degree of immunity of a crop against killing frost. The bottom of a valley collects all the cold air flowing during the night from the neighbouring slopes. The farmer should try to avoid such localities for growing crops which are susceptible to frost. Slopes are less liable to frosts as the cold air cannot collect on them and are therefore to be preferred for horticultural gardens.

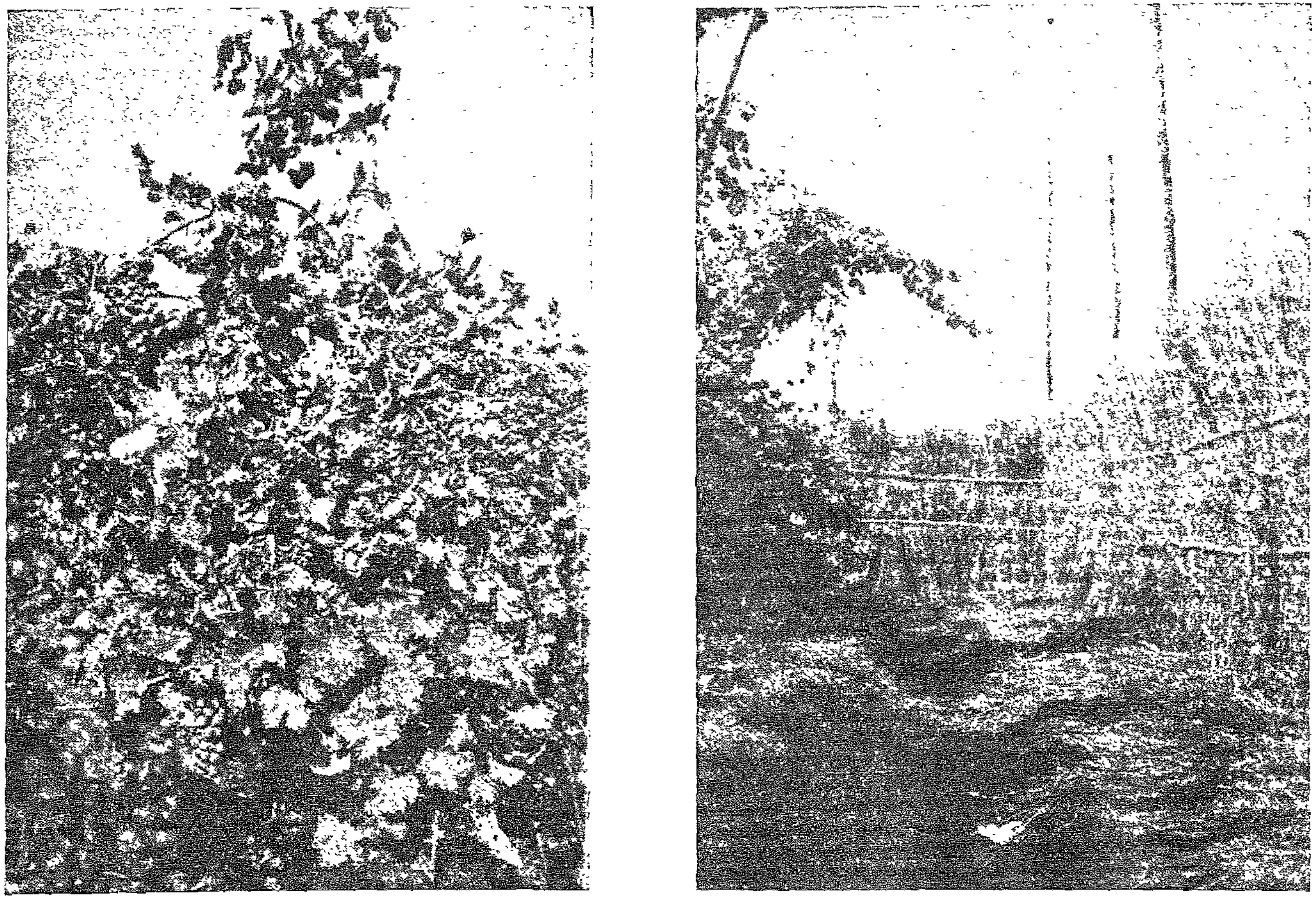
Heaters and wind-breaks.—During cold waves in India there is often a flow of cold air over the country. Across avenues the flow of air is checked by wind breaks and the cooling of vegetation on the lee-side of such wind breaks is found to be less severe than on the windward side. In many crops like sugarcane and vines, it is possible and often worthwhile to try heating the garden by means of artificial heaters after reducing the air movements by means of wind breaks. *Fig. 13* shows a vine crop killed by frost at Nasik in January 1935, when the loss due to frost amounted to several lakhs of rupees in that district. The figure on the right shows the wind-break of jowar stalks tried out in one of the gardens. Bright fires are found to be most effective. But the Indian farmer is not rich enough to try oil heaters of the type used in America. At Nasik it was found that it was possible to heat up a vine garden by as much as 10°F by using 400 country fires (dried leaves, twigs, etc.) per acre when the garden was protected by wind breaks. The Agricultural Meteorology Section has devised a simple frost alarm device which rings a bell and wakes up the farmer as soon as the temperature in the garden begins to approach the freezing temperature and heating operations ought to be commenced.

Within short crops like wheat, it is more difficult to alter the local climate by the artificial methods of heating or smudging. The use of irrigation to prevent crops from frost damage has been advocated. This may be useful during cold waves of short duration. During protracted spells of cold, however, a considerable amount of the heat from the sun by day is lost by simultaneous evaporation from the wet soil and the protection afforded by irrigation tends to be counter-acted. The subject of frost protection in India deserves further study. The damage due to frost is very large in some areas as is apparent by the revenue remissions amounting to several lakhs of rupees granted by the Provincial Governments and Indian States in North and Central India.

6. **Heat Waves.**—Just as cold waves are injurious to crops in winter, heat waves in summer are prejudicial to their well-being. The frequencies of days with abnormal high air temperatures, *e.g.*, 100°F, 105°F, 110°F etc., have been computed for a network of stations in India. From charts showing these frequencies, it is clearly seen that the centre of high frequency of maximum temperatures of 100°F and over lies in the Deccan and the Central parts of India during March, April and May. The frequency increases from 20 in March to 30 in May over the Deccan but once the monsoon sets in, the centre of high frequency shifts towards Northwest India. In July and August, Madras Southeast is another centre of high frequency. Frequency of 105°F and over show very similar tendencies.

7. **Excessive or defective insolation.**—*Abnormal, i. e., high or low, soil temperatures.*—Insolation is a function of the inclination of the solar rays, the length of the day and the transparency of the atmosphere. During clear days in summer, soil temperatures in countries like India reach very high values, particularly on days when air movement is weak. Experiments made at Poona show that on such days a thin cover of white substance like chalk can depress the soil temperature at noon by as much as 18° to 20°C. A black cover is useful for absorbing the insolation fully and heating up the soil layers as much as possible during days with weak insolation. The effect of wetting the surface is to depress the soil surface temperatures by about 15°C. But the cooling effect is due to heat loss by evaporation and lasts only as long as there is enough moisture in the soil. Recent experiments made at the Central Agricultural Meteorological Observatory at Poona show that a thin layer of chalk or a surface mulch of ' bagasse ' helps not only to keep the soil layers cool but also to conserve the soil moisture.

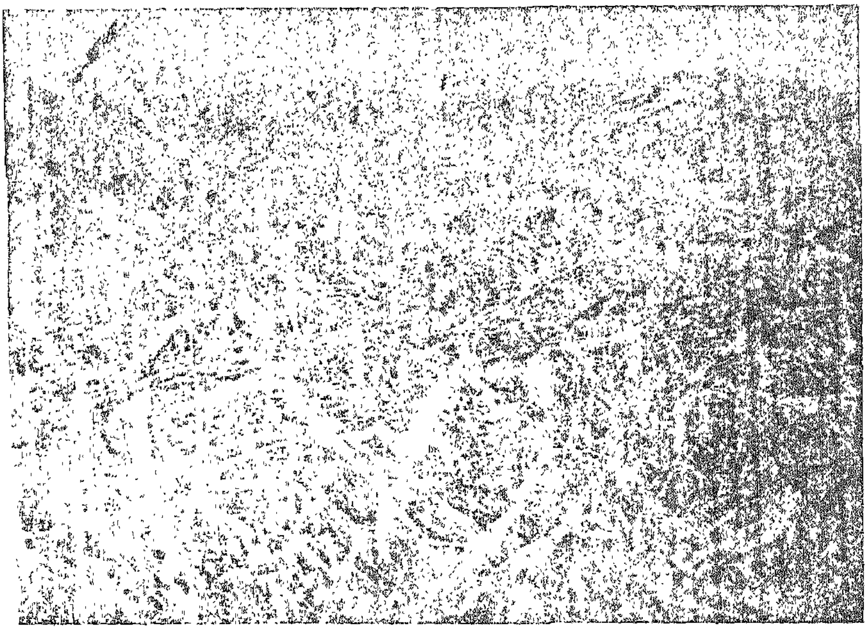
The fundamental importance of clear sunshine to photosynthesis in plants is well known. During cloudy weather this activity is decreased, thus retarding growth.



A VINE CROP KILLED BY FROST. WIND-BREAK OF JOWAR STALKS IN VINE GARDEN.

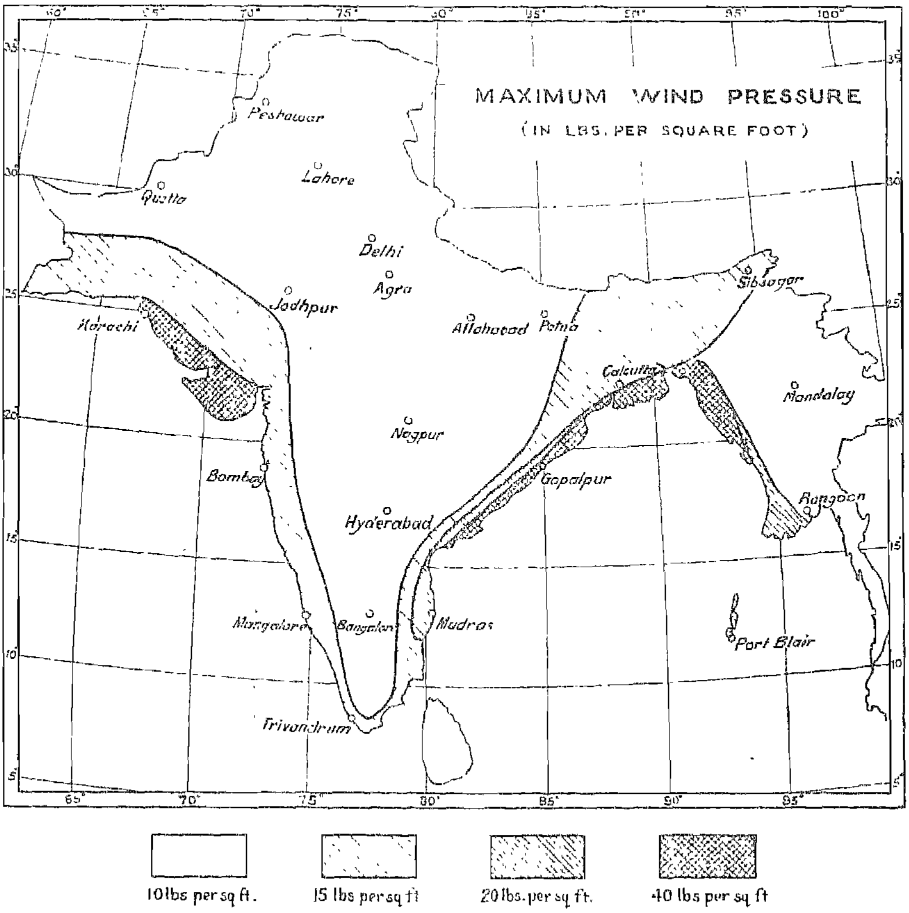
FIG. 13. FROST IN THE NASIK DISTRICT.

G. P. Z. P. Poona. 1916



FIG, 14. JOWAR CROP LAID LOW BY HIGH WINDS AT POONA.
(OCTOBER 1938)

G. P. Z. P, Poona, 1946.



Areas have been hatched to indicate regions in which the wind pressure is not likely to exceed the values shown for each hatching except in such short lived accidents as tornadoes and severe thundersqualls

FIG. 15.

G R2.P. POONA. 1946.

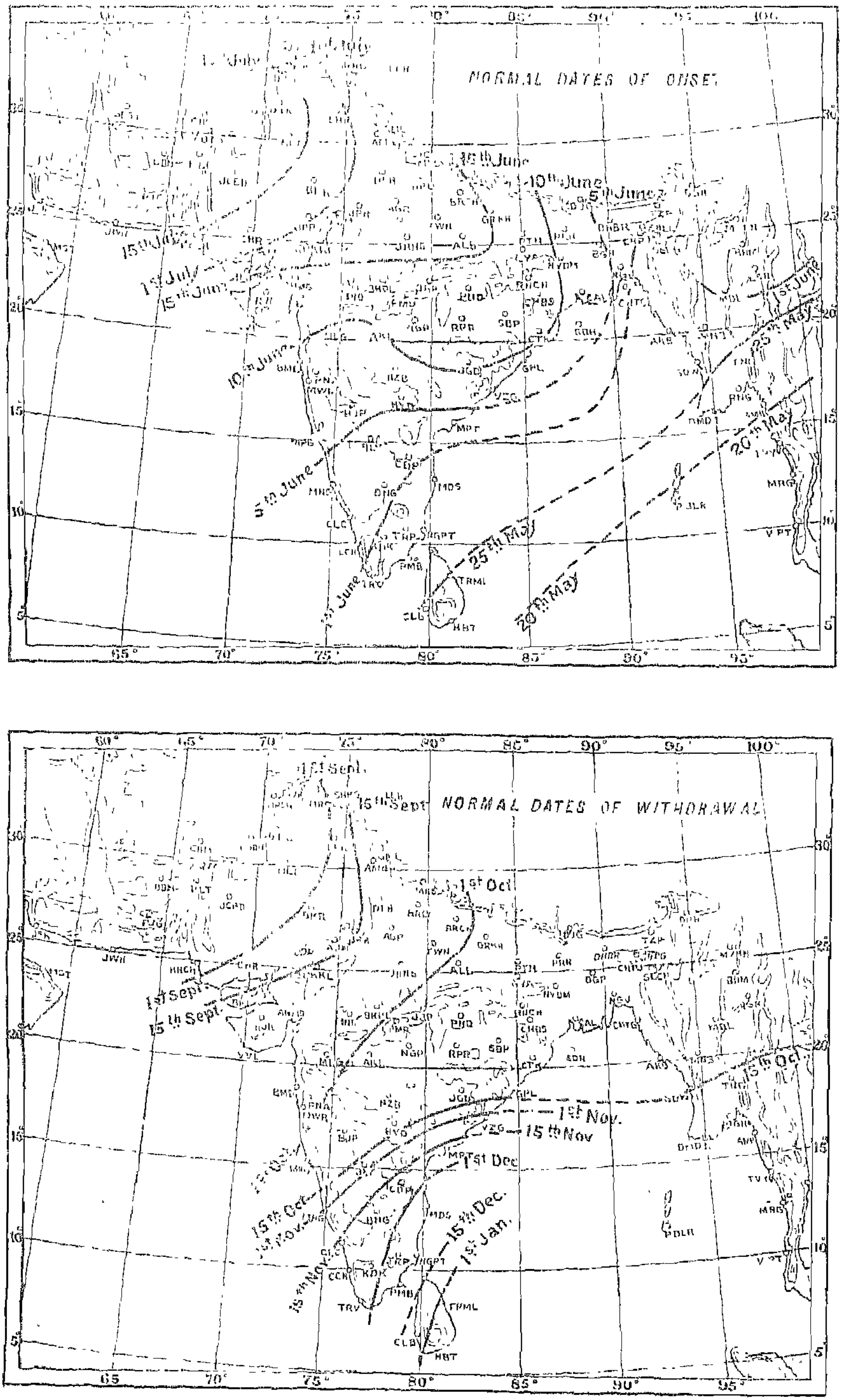


FIG.16. THE SOUTHWEST MONSOON: NORMAL DATES OF ONSET AND WITHDRAWAL.

Also, conditions become favourable for the incidence of certain diseases and pests. Cloudiness is also injurious to crops during certain critical epochs like flowering.

8. **High Winds.**—The effects of high winds are many. The mechanical effect and possible damage to standing crops are obvious. *Fig. 14* shows a crop of jowar at Poona laid low by high winds.

If the air is cold, the effect of the high winds is to cool objects very rapidly and the result of such cooling of plants is disastrous if frost sets in. On the other hand, if the air is hot, the saturation deficit would be high and the rate of evaporation from water reservoirs and transpiration from plants and trees will increase enormously. On such occasions plants are known to wilt and die owing to the rapid desiccation. The shrivelling effects of hot winds on grains at the milk stage is well known.

It is at once obvious that the clear sweep of the winds over crop fields should be checked. Wind breaks are the only remedy. Wind breaks should consist of a line of trees planted at right angles to the prevailing wind direction. When the trees grow up, the gaps between them must be blocked by growing another line of trees or shrubs. The United States of America has considerable experience on this subject. " An ideal wind break for checking wind currents would have the contour of an earth dam. In the central rows would be planted the tallest trees such as cotton-wood ; on either side, rows of shorter trees, such as ash and locust ; and outside of these, low bushes or cedars. Such a wind break would not be easily penetrated and its inclined surface would direct the air currents upwards and relieve the horizontal wind pressure ". (Farmers' Bulletin No. 1405).

In India we have to lay down similar specifications for an ideal wind break. The numerous effects of a wind break may be stated as follows :—

(*i*) Checking air movement and thus affording protection to fields and orchards ;

(*ii*) Checking of the movements of the top-soil and consequent prevention of dust-storms in areas where the soil is sandy or very fine ;

(*iii*) Reducing evaporation. This happens in two ways : *viz.*, by reducing wind velocity and by decreasing saturation deficiency (due to water transpired by the trees) ;

(*iv*) Giving shade to the farmstead ;

(*v*) Older trees would serve as timber and can be replaced by younger plants.

The experience in America is that loss due to the space taken up by wind breaks and due to the water removed from the fields by the root-systems of the trees and shrubs is more than made up by the increased yields in the protected area and by the value of timber.

During severe weather disturbances like cyclonic storms, depressions, thunderstorms, etc., squalls or high winds are experienced. *Fig. 15* shows the maximum wind pressure likely to be attained in different parts of the country. It may be noted that exceptionally high wind pressures are experienced mainly in the coastal tracts of the country.

Before concluding this chapter it may once again be stressed that a nation-wide awakening in regard to the planting of trees according to a well considered and well organised plan is required not only with respect to our denuded forests but also the rural parts of our country.

CHAPTER IV.

THE CROP-WEATHER CALENDAR.

There can be no doubt that the farmer stands to benefit by warnings for adverse weather when these are received by him expeditiously. For example, if he knows when the monsoon rains are likely to begin (*Fig. 16* shows the normal dates of onset and withdrawal of the monsoon in different parts of India) and later how the rainfall would vary during the season, when breaks are expected and when there will be a resumption of wet weather he will be able to time the various important cultural operations like preparation of seed bed, manuring, sowing, interculture, weeding, transplanting (in the case of rice). harvesting, threshing, drying, etc., with minimum risk to the crop and utilise his limited resources as regards labour, manures, etc., to maximum advantage. There are *critical periods* in the life history of a crop from the date of sowing to the date of harvesting. Sowing time is one of no small anxiety to the farmer. He knows that a heavy shower just after sowing will wash away the seeds and seedlings and depress considerably the germination percentage. (*Fig. 17* shows the germination percentage of wheat sown *before* and *after* a period of showers at Poona). Again, if after sowing is completed, a prolonged drought follows, the tender seedlings would wither away and the entire crop may need re-sowing. It is also well known that the weather at sowing time even determines the nature and variety of the crop that the farmer decides to sow on his field. If conditions are favourable during the first phase (germination and early vegetative growth) the crop gets a good start in its career. Thereafter, intervals of clear weather are required for interculture and weeding. During the period of rapid vegetative growth or the " grand " period as it is called, the water requirement and need for sunshine for photosynthesis are maximum. Then follows the period of flowering and reproduction, when vegetative growth has ceased.

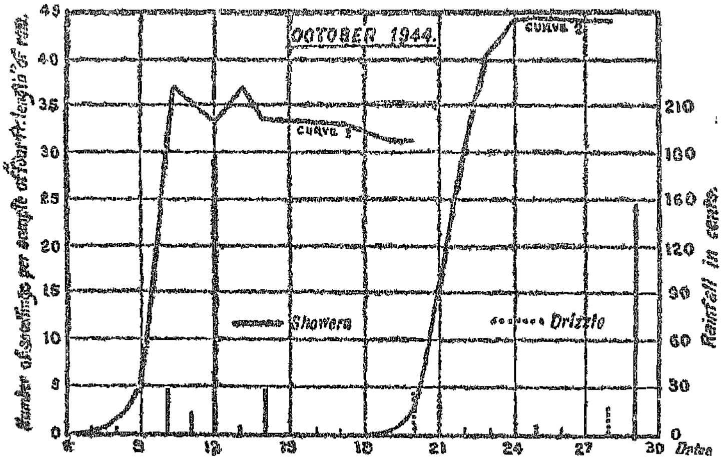


FIG. 17 PROGRESS IN GERMINATION OF WHEAT VARIETY " BANSIPALLI 808 " UNDER TWO CONDITIONS.

(1) No rain before the start of germination but heavy showers during germination. Germination % only 77·0 %.

(2) Drizzle (25 cents only) before the start of germination but practically no rain during germination. Germination 92·8 %. Germination % Laboratory—93·0 %.

This period of flowering, fertilising and grain-formation needs clear weather and minimum cloudiness. Cloudy wet weather during this period can ruin a crop, very promising till then. When the earheads are forming and the grains are in the milk stage one day's hot winds can shrivel up the grains. Even after the entire season has been passed safely, the crop is not free from the danger of adverse or unexpected weather. A heavy shower of rain or hail can do incalculable damage. If warned in

CROP WEATHER CALENDAR

PROVINCE : United Provinces.
DISTRICT : SITAPUR.
CROP : WHEAT (Irrigated)

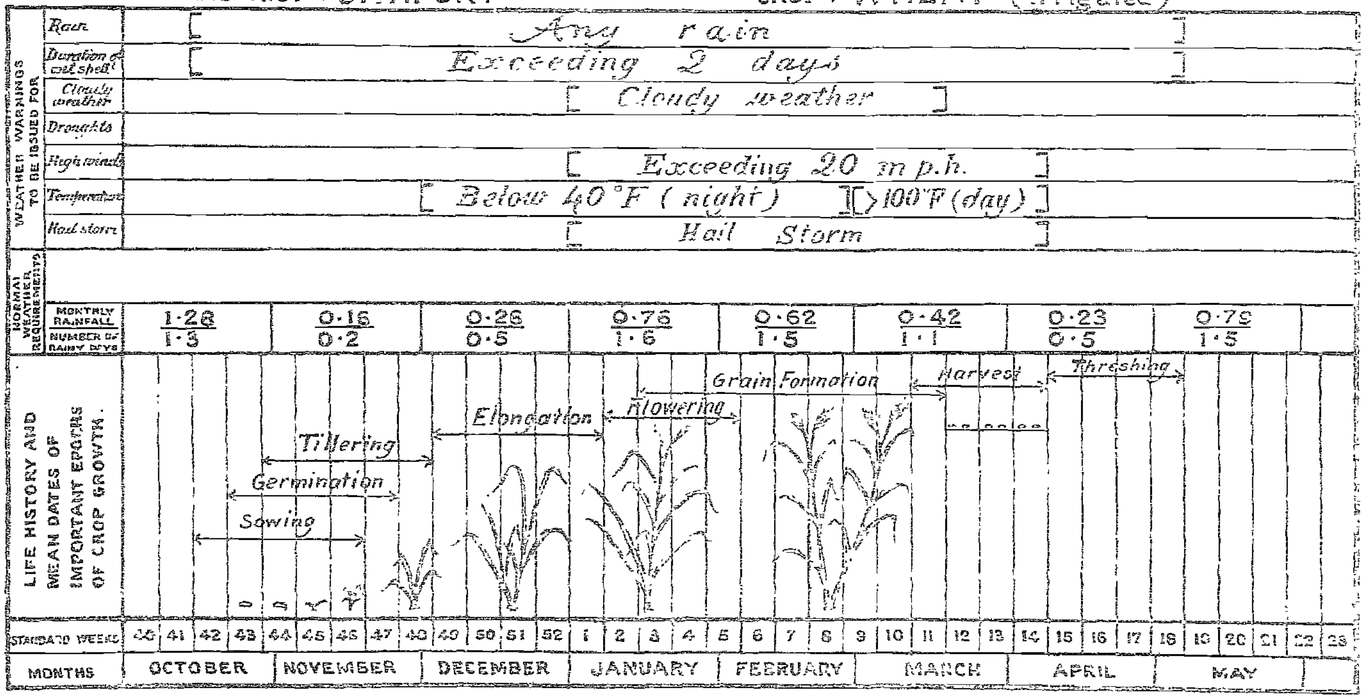


FIG. 18.

G.P.Z.P. POONA 1946

CROP WEATHER CALENDAR

PROVINCE : Madras.
DISTRICT : RAMNAD.
CROP : RICE (Irrigated)

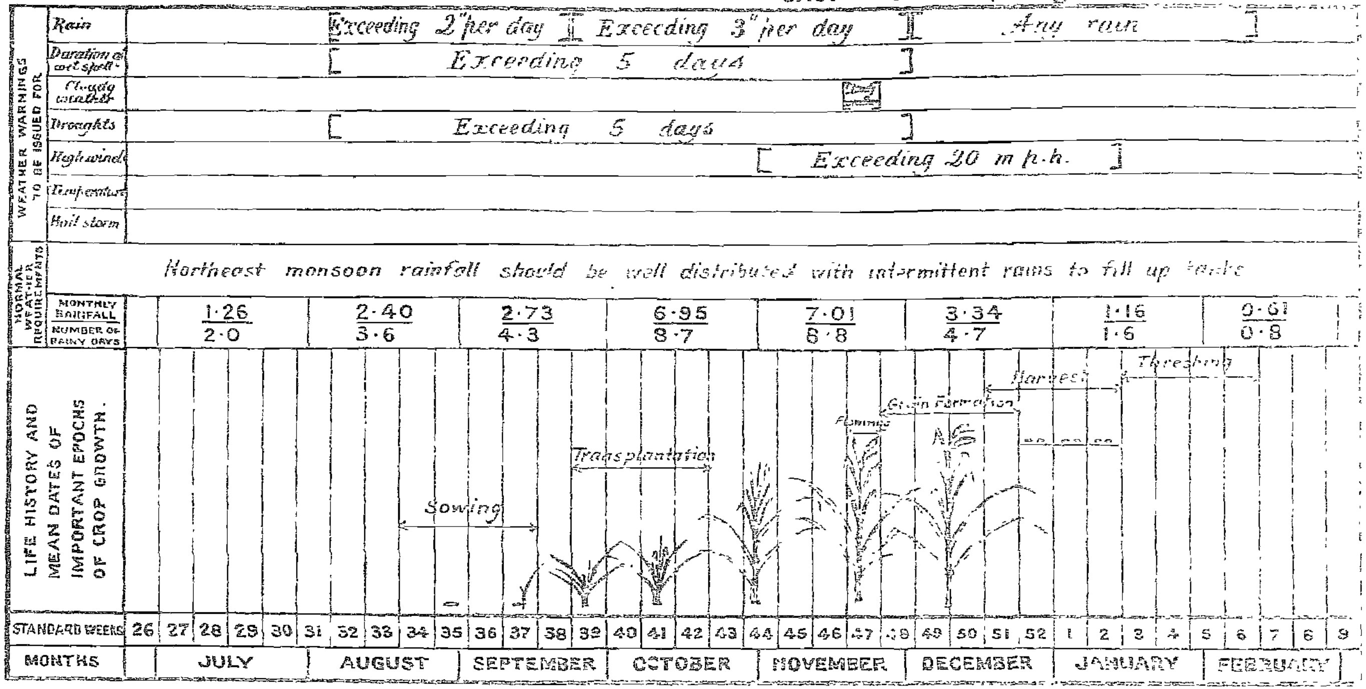


FIG. 19.

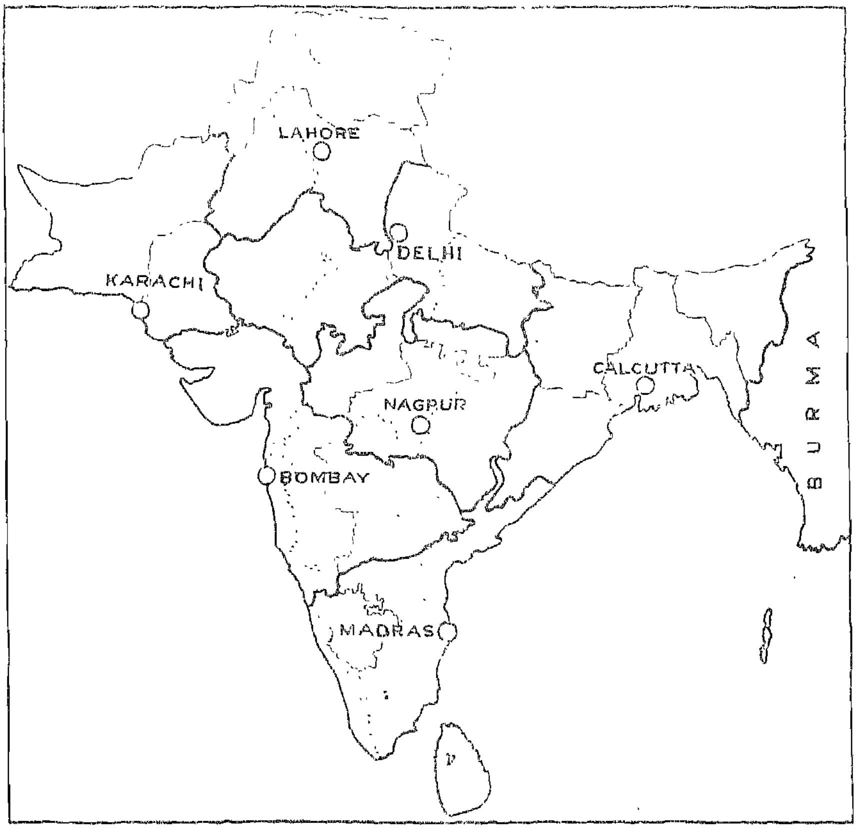


FIG. 20. AREAS UNDER SEVEN REGIONAL CENTRES.

time the farmer would hurry up his harvesting operations. Later, when the harvested crop is lying on the threshing floor, it is again at the mercy of any sudden showers.

The weather has also another indirect control. Crops are liable to attacks of various diseases and insect pests during the season. The intensity of their incidence is dependent upon certain favourable weather conditions. One need be reminded only of the cereal rusts and the locust invasions to realise how many major enemies the cultivator has to contend with.

The normal weather requirements, critical phases etc. vary from crop to crop and with locality. In 1943, the Agricultural Meteorologist issued a very detailed questionnaire to the various agricultural departments in India to find out the dates of the principal cultural operations and important growth phases relating to different crops as well as their normal weather and warning requirements. Districtwise replies were received. These are the basis of the first edition of the "Crop-Weather Calendars". These Crop-Weather Calendars refer to each principal crop in each district and are of great value to forecasting officers. *Fig. 18* shows the calendar for wheat for the district of Sitapur in the United Provinces and *Fig. 19* gives it for rice in the Ramnad district in the Madras Presidency. These calendars are provisional, to serve the immediate needs. They would require periodical revision in the light of actual experience. It must be kept in mind also that as the farmer gets used to the daily weather bulletins and adjusting his programme accordingly, the Crop-Weather Calendar too would in a few years' time adjust itself to the weather sequence in a more rational manner than it apparently does at present. At present, as each individual farmer is exercising his own judgment there is considerable random variation in the dates of the important cultural operations from place to place even in neighbouring localities.

CHAPTER V.

THE METEOROLOGICAL ORGANISATION FOR ISSUE OF WEATHER BULLETINS TO FARMERS.

Dissemination of weather bulletins.—There are 7 Regional Forecasting Centres : Calcutta, Delhi, Lahore, Karachi, Bombay, Nagpur and Madras. *Fig. 20* is a map showing the seven regions and the stations from which weather bulletins are to be issued. These will also be All-India Radio Broadcasting Stations so that the weather bulletins for farmers may be issued daily as part of the rural programmes. For the efficient reception of the weather reports it will be essential that a sufficient number of radio receiving sets are kept functioning in the various district and tahsil headquarters and in other rural centres of the country. This aspect of dissemination is *extremely important* and will no doubt form an urgent item of Post-War Developmnet.

Nature of the weather reports and warnings.—It has been mentioned in Chapter IV that these should be according to the requirements indicated in the Crop-Weather Calendar. The weather reports and warnings will try to indicate :

1. Dates of first onset of rain at sowing time and the probable rainfall intensity and duration ;
2. Breaks in rain and their probable duration ;
3. Date of re-start of a period of rain ;
4. Spells of heavy rainfall ;
5. Untimely rainfall ;
6. Warnings for adverse weather phenomena like floods, frost, hail, squalls, etc., and their probable intensity, duration and distribution in space.

There are some points to be borne in mind in judging these bulletins.

The net-work of daily weather reporting stations (observatories) is rather open in some parts of India, there being often only one reporting station representing a group of districts. It will, therefore, be necessary in such cases to deal with blocks of districts instead of the individual districts.

There is a considerable variation as regards the climatic homogeneity of different parts of the country. Rainfall during any particular spell of wet weather will be much more variable both with respect to time as well as locality in some parts of the country than in others. In districts of Rajputana, for example, the rainfall at neighbouring stations on a particular day may be more sporadic and variable than in an area like Malabar, Konkan or Bengal.

Weather phenomena in a tropical country like India have a tendency to occur distributed not always continuously but discontinuously like bubbles in a pan of boiling water. When the temperature of water is increasing and approaching 100°C, one can say generally that the water is going to boil, but whether at a particular point there is going to be a rising bubble or not, it is impossible to say.

The present position of the science of weather prediction from the daily weather charts (synoptic meteorology) is such that forecasts and warnings can be issued ordinarily 36 to 48 hours ahead, and in the case of major phenomena associated with storms and depressions 48 to 72 hours ahead.

Phenomena like thunder-storms and hail-storms are often very sporadic in their distribution and it may not always be possible to predict them accurately.

When the monsoon conditions have not been established, and the monsoon is late in arriving (or when there is a break in the monsoon), it may be possible to indicate in a general way that the cultivators will get little or no rain for a few days. But this forecasting for a few days under all conditions comes under the category of " Medium Range Forecasting " which yet requires much study. For agricultural purposes, the medium range forecasting is of very great importance. This is one of the important subjects which are receiving the attention of the Meteorological Department.